Thermal Comfort and Sleep Quality

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Human comfort is determined based on their comfort level and overall satisfaction with the thermal environments. A stable core body temperature at about 37°C and maintained through a process that called Thermoregulation. In the process, the body would adjust to the thermal surrounding through efferent responses such as sweating or triggering adaptive action to be taken by each individual such as drinking water, having bath or etc. This is done so that are a certain level of comfort is reached in the cognitive process of a human that is called thermal comfort where comfort with surrounding temperature is archived physically, physiologically and psychologically.

Sleep is one of the most important aspects in daily life of a human being. It is classified into a few different stages, mainly Stage N1, N2, N3 and REM. This cycle alternates a few times during the whole sleep. An extreme cold environment would result in disrupted sleep quality as well as extreme hot environment. Thus, evaluating both thermal comfort and sleep quality are equally as important.

In investigating thermal comfort with sleep quality, the method of questionnaire evaluation on the comfort of an individual have been the most used, since the thermal comfort considered as an individual perception. However, as the technology advances, other type of assessments are also used in addition to the traditional questionnaire evaluation method.

Keywords: thermal comfort ; air conditioning ; bedroom ; sleep quality

1. Introduction

In the modern era, the usage of mechanical devices has become a necessity in archiving thermal comfort whether in hot or cold environments. For a tropical climate such as Malaysia, the usage of air conditioners (AC) has seen a steady increase in the recent years. According to the survey data from the Department of Statistics Malaysia [1], 22.3% of households in 2010 owned air conditioners, which is an increase of 16.2% from the year 2000. Most of the usage occurs in bedrooms, which indicates that air conditioners are mainly used during sleeping hours [2][3]. This usage pattern contributes to the larger power demand for households at nighttime compared to the daytime. For example, Ranjbar et al. [4] conducted a survey in a low-cost public apartment building in an urban area of Kuala Lumpur, Malaysia, and reported that seven out of ten houses were equipped with AC in bedrooms; they also found that the peak demand occurred between 22:00 and 07:00 due to AC usage during the sleeping period. In addition, Mekhilef et al. [5] reported that the average usage of AC overnight was 1086 kWh, higher than the daytime AC usage of 730 kWh per year in a high-rise residential building in Kuala Lumpur. Kubota et al. [6] conducted a survey on energy consumption and AC usage in terrace houses in Johor Bahru, Malaysia, and found that 80% of the respondents switched on the AC by 23:00 and that more than 50% of them continued to use AC until 05:00. In the study by Ono et al. [7] that involved multiple dwellings in Kuala Lumpur, AC usage was found to be mostly frequent at nighttime, including the sleeping period. The usage pattern is not only found in Malaysia but also in other countries during the summer seasons. Lan et al. [8] reviewed past studies on AC usage in bedrooms; they reported that high AC usage in bedrooms during summer in Shanghai, China, and Hong Kong. In addition, they pointed out the importance of further studies to reduce AC usage during the sleeping period. From these studies, there is no doubt that most of the AC usage in the residential dwellings occurs during nighttime and during sleeping hours. Further investigating the usage during these hours and strategies in reducing the usage would be useful in reducing the energy consumption by households during these hours.

2. Air-conditioners Usage for Sleep Thermal Comfort

Sekhar [9] pointed out that people living in hot and humid climates prefer to have low AC temperature settings. In fact, the questionnaire survey by Ekasiwi et al. [10] reported that the average AC temperature during sleeping hours was 22 °C for residential buildings in Kuala Lumpur. This is lower than what is recommended by the Malaysian government, which is 24 °C [11]. The behaviour is also found in other countries such as Japan. Muro [12] obtained the setpoint temperature by gender in Japan through a survey and found that male respondents preferred a lower setpoint temperature (average of

26.5 °C) than female respondents (average of 27.2 °C). A low setpoint temperature of cooling during sleeping hours will increase the electricity consumption and may induce sleep disorder and health deterioration. For example, Lin and Deng [13] reported that around 60% of respondents experienced sleep disorder with the AC in operation. Ekasiwi et al. [10] also found that 27% of respondents in Kuala Lumpur had symptoms related to the low temperature living. Haskell et al. [14] found that rapid eye movement (REM) sleep and stage 2 sleep at 21 °C decrease compared to sleep conditions at the thermoneutral temperature. Similar results were found by Candas et al. [15], Palca et al. [16] and Sagot et al. [17].

3. Clothing and Bedding Effect

Clothing and bedding type or insulations are also found to affect both thermal comfort and sleep quality. Lin and Deng [18][19] studied thermal comfort in sleeping environments by measuring the total insulation of the bedding system commonly used in the subtropics and established a thermal comfort model for sleeping environments. Jaafar and Croxford [20] and Jaafar [21] studied the effect of different covers (blanket and comforter) on the thermal neutrality of occupants in Malaysia. The study found that occupants who slept with a comforter had thermal neutrality of 2.3 °C lower compared to the blanket users. Shin et al. [22] conducted a study on different sleepwear fabrics under different ambient temperatures during a sleep period. Okamoto-Mizuno et al. [23] studied the effects of different materials used as a bedsheet and a bed pad in Japan; they found that the cotton bedsheet and the polyester bed pad improve the sleep quality significantly compared to the linen bedsheet and bed pad.

4. Evaluation Methods

The questionnaire survey such as the ASHRAE 7-point scale [24] is widely used in studies of thermal comfort, especially in waking up state. Sleep quality evaluation using a questionnaire survey is also widely used in the form of Pittsburgh Sleep Quality Index (PSQI) and its variations. Both of these questionnaires are adopted in a study by Zhang et al. [25] which also found that the most satisfactory operative temperature was at 24.2 °C, with subjects having a lower neutral temperature and a broader accepted temperature range during sleep. In addition, Imagawa and Rijal [26] also adopt the questionnaire surveys in investigating the thermal comfort, sleep quality, and behaviour of occupants in the bedrooms of Japanese houses during the hot and humid season. The study found that the mean comfort temperature during the hot and humid season is between 26.4 and 27.1 °C. Questionnaire surveys are also used in a study by Kim and Kum [27], who investigated the thermal comfort during sleep during summer in Korea. The study concludes that the sleep quality is the best at 26 °C and worst at 30 °C. The same approach is also adopted in studies by Liu et al. [28] and Wang et al. [29] which found that the best sleep quality is at the indoor operative temperature of 15.8 °C.

The use of a subjective questionnaire survey, especially in evaluating sleep quality have its own limitations, as pointed out by Lan and Lian [30]. Thus, some studies have adopted the use of an objective sleep quality measurement device, such as an electroencephalogram (EEG) device to capture vital signs. For example, Lan et al. [31] conducted experiments on the thermal comfort of occupants during sleep periods at three air temperatures, i.e., 23 °C, 26 °C, and 30 °C, using an EEG device to evaluate sleep quality. The study found that the air temperature greatly effects sleep quality, with a large difference in neutral temperature between the waking up state and sleeping state. Pan et al. [32] conducted experiments with a similar evaluation method for three different air temperatures, i.e., 17 °C, 20 °C, and 23 °C, and found that the temperature of 23 °C provides the best sleep quality of all three temperatures. While the EEG is a very accurate device in capturing vital signs related to the sleep stages, it is also a very expensive and sophisticated device. Apart from the use of EEG, a simpler device in measuring sleep quality in the form of a wrist wearable device could also be used. A study by Tsuzuki and Mori [33] adopted the use of a wrist actigraphy device in evaluating sleep quality of occupants in 22 Malaysian houses. The study found that the sleep quality decreases with increased air temperature and air velocity. Commercially available wrist wearable devices such as a Garmin or Polar activity tracker are also found accurately measure sleep data, as pointed out in studies by Brooke et al. [34], Lee et al. [35] and Spielmanns et al. [36]. Therefore, the combined use of a questionnaire survey and a wrist wearable device in evaluating both thermal comfort and sleep quality could be explored.

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